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Applications of remote sensing in the Boston Urban Studies Program

Part I

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CRREL Report 77-13

Applications of remote sensing in the Boston Urban Studies Program

Part I

Carolyn J. Merry and Harlan L. McKim

June 1977

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The cost effectiveness of remote sensing techniques was compared to that of the conventional techniques used by the U.S. Army Engineer Division, New England, in the Boston Harbor – Eastern Massachusetts Metropolitan Area study. A total of 6 level I, 18 level II, and 18 level III land use categories were mapped from NASA RB-57/RC-8 high altitude aircraft photography for six selected 7½-minute quadrangles located in the Boston area. Watershed and political boundaries could not be mapped from the NASA photography. Impervious surfaces and curb lengths were mapped from low altitude aircraft photography obtained with a Zeiss RMK 15/23 camera system (measured scale 1:3500) for two sites in the Boston South and Newton quadrangles. The remote sensing procedures used in this study usually provided much greater detail than conventional procedures. The remote sensing procedures were not Over

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always cost-effective when compared to the conventional procedures, but they were always more accurate. Therefore, remote sensing techniques should be used and appropriate photographic resolution and scale factors taken into consideration when mapping land use, curb density and impervious surfaces for use in the STORM (storage, treatment, overflow, runoff) model.

PREFACE

This report was prepared by Carolyn J. Merry, Research Geologist, and Dr. Harlan L. McKim, Research Soil Scientist, Earth Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory. The project was coordinated with Saul Cooper, Chief, Water Control Branch, Engineering Division, U.S. Army Engineer Division, New England (NED). The study was funded by the Directorate of Civil Works, Office, Chief of Engineers, under Order No. CWP-S-75-10.

The authors express their appreciation to Richard DiBuono and David Buelow of NED for technical review of the report and for their input on the NED costs and techniques used in the Boston Harbor-Eastern Massachusetts Metropolitan Area study; and to the following CRREL personnel: Thomas L. Marlar for his assistance as a photographer in acquisition of the low altitude photography; Lawrence Gatto for technical review of the report; Eleanor Huke for her assistance in preparation of the map overlays and figures and for field assistance; and Harold Larsen, Matthew H. Pacillo and Heidi A. Deering for preparing the final land use maps.

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CONTENTS

ILLUSTRATIONS

TABLES

SUMMARY

The primary objective of this study was to compare the cost effectiveness of remote sensing techniques with that of conventional techniques used by the U.S. Army Engineer Division, New England (NED), in the Boston Harbor-Eastern Massachusetts Metropolitan Area study. The following parameters were quantified for use in the STORM (storage, treatment, overflow, runoff) model: 1) area of a watershed, 2) land use type in a watershed, 3) impervious surface area for a land use type, and 4) curb length for a land use type. The secondary objective was to assess the utility of remote sensing in the delineation of water bodies, drainage patterns, and watershed and political boundaries.

A total of 6 level I, 18 level II, and 18 level III land use categories were mapped for six selected 7½-minute quadrangles located in the Boston area. These units were delineated from black and white photomosaics prepared from NASA RB-57/RC-8 high altitude aircraft photography enlarged to a scale of 1:24,000. The photography provided adequate detail for land use mapping of the categories used in the STORM model. The total cost of the land use mapping using remote sensing techniques was $0.014/acre or $2890 for the six quadrangles. This compared with costs of $0.003/acre or a total of $600 using conventional techniques. The conventional procedure did not include the cost of photographic data products, enlargement of photography or the assembling of photomosaics.

Watershed and political boundaries could not be mapped from NASA high altitude aircraft photography. This information would have to be obtained by interpreting contour elevations from existing USGS topographic maps. However, hydrologic features such as lakes and streams could be delineated on a cost effective basis.

Impervious surfaces were mapped from low altitude aircraft photography obtained with a Zeiss RMK 15/23 camera system (measured scale 1:3,500) for two sites located in the Boston South and Newton quadrangles. The percentage of impervious surface determined using remote sensing techniques compared favorably with the values calculated by conventional techniques. The cost of using remote sensing techniques to measure impervious surface percentages was $1.55/acre; however, there was not sufficient information available to compare these costs with the conventional procedures used by NED. Since all highways, parking lots, roads, etc. were easily delineated using the remote sensing techniques, the remote sensing method would be much more accurate than the method employed by NED.

A random-dot statistical method was used to obtain a total ft/acre curb length measurement for the various land use units. More than 64% of all curbs in the Newton site were identified from the low altitude aircraft photography. The curb density for each land use found by conventional techniques varied with the degree of urbanization when using residential density as an index of urbanization. The cost of curb density mapping was $0.90/acre using remote sensing techniques and $1.20/acre using conventional techniques. The accuracy of the measurement of curb length made using conventional techniques could not be determined because ground truth data were not obtained.

The remote sensing procedures used in this study usually provided much greater detail than conventional procedures. The increased accuracy provides more confidence in the predictive capability of the STORM model. The remote sensing procedures were not always cost effective when compared to the conventional procedures but they were always more accurate. Therefore, remote sensing techniques should be used and appropriate photographic resolution and scale factors taken into consideration when mapping these parameters, specifically land use, curb density and impervious surface for use in the STORM model.

CONVERSION FACTORS: U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

These conversion factors include all the significant digits given in the conversion tables in the ASTM *Metric Practice Guide* (E 380), which has been approved for use by the Department of Defense. Converted values should be rounded to have the same precision as the original (see E 380).

Multiply	*By*	*To obtain*
inch	25.4*	millimeter
foot	0.3048*	meter
mile (statute)	1.6093	kilometer
acre	4046.873	$meter^2$
$mile^2$	2.589998	$kilometer^2$

* Exact

APPLICATIONS OF REMOTE SENSING IN THE BOSTON URBAN STUDIES PROGRAM

Carolyn J. Merry and Harlan L. McKim

INTRODUCTION

Background

During the last five years the prediction of the quality of urban stormwater runoff has been critically evaluated. The Boston Harbor-Eastern Massachusetts Metropolitan Area (EMMA) study, initiated in 1973, presented an inventory of data on the quality and quantity of stormwater runoff in 109 communities in the Boston area (U.S. Army Engineer Division, New England, 1973a). Other cities that have been studied include Chicago, Tulsa, Baltimore and Cincinnati. The approach used in these studies was to relate, primarily through statistical analysis, observed runoff pollutant loads to the physical and environmental characteristics of a watershed.

A study conducted in Chicago by the American Public Works Association is the source of information on the methodology for predicting the quality of stormwater runoff (American Public Works Association 1969). A major finding of this study was that litter, primarily the dust and dirt along curbs and in gutters, contributes significantly to pollution in urban areas. In fact, the results indicated a direct correlation between the concentration of runoff pollutants and dust and dirt buildup on the streets.

Literature review

The computer simulation models now available for predicting the quality of stormwater runoff are generally based on the Chicago study. One comprehensive model is the EPA Stormwater Management Model developed by Metcalf & Eddy, Inc., the University of Florida, and Water Resources Engineers, Inc. (Lager et al. 1971). This model for stormwater management simulates stormwater runoff, wastewater flow in dry weather, flow routing, wastewater storage and treatment, and the quantity and quality responses of receiving waters (Lager et al. 1971). The stormwater runoff portion of the Lager model estimates the quantity and quality of stormwater runoff from overland flow. It also produces, for a given storm event, based on rainfall and system characterization, estimates of the volume of runoff and five-day biochemical oxygen demand (BOD_5). A sensitivity analysis of the stormwater runoff portion of the simulation model showed the importance of impervious area and specific curb length for a specific land use type, and identified the significant effects on the BOD_5 (Graham et al. 1974). Impervious area and specific curb length equations in conjunction with demographic projections were determined and used in predicting non-point source pollutants added to a receiving water from adjacent urbanized watersheds (Graham et al. 1974).

The model discussed in this report is STORM (storage, treatment, overflow, runoff model), developed by Water Resources Engineers, Inc. for the Corps of Engineers Hydrologic Engineering Center (Hydrologic Engineering Center 1975). The STORM model addresses only the quality and quantity of stormwater runoff and the interaction of treatment, storage and overflow.

The STORM model considers the interaction of six components of the urban stormwater cycle:

1. Rainfall/snowmelt
2. Runoff
3. Pollutant accumulation
4. Treatment rates
5. Storage
6. Overflows

The interaction of these components is studied by first analyzing the input data that physically describe the urban area and then computing the quantity and quality of runoff produced by a given rainstorm. Rainfall data may come from historic records, or a synthetic design storm may be used. Runoff is computed by a modified rational method that makes the model most applicable to small watersheds up to 5 square miles in area. Pollutant loads that can be predicted are:

1. Suspended and settleable solids
2. Five-day biochemical oxygen demand (BOD_5)
3. Nitrogen
4. Orthophosphate

The data necessary to apply the model accurately include:

1. Amount of rainfall
2. Duration of dry period preceding rainfall
3. Area of watershed
4. Runoff coefficients for pervious and impervious areas
5. Street sweeping efficiency and frequency
6. Amount of water storage in depressions
7. Daily evaporation rates
8. Land use
9. Percent imperviousness* of each land use group
10. Length of street gutters† for each land use group
11. Pollutant data – accumulation rates and composition of dirt and dust
12. Various combinations of treatment rates and storage amounts

In this list remote sensing techniques can best be utilized to quantify 3, 8, 9 and 10. For example, photointerpretation techniques were used to estimate imperviousness and specific curb length in a study conducted in metropolitan Washington, D.C. The primary criterion observed on NASA color infrared aerial photography (scale 1:50,000) was color contrast between vegetation associated with pervious and impervious areas. The curb length data in this study were calculated based on the assumption that both sides of the streets were curbed.

Computer interpretations of Landsat multispectral data have also been used to determine land use and impervious area percentages. One technique assigns an average percent of impervious area to land use types and then attempts to classify the Landsat data into land use categories (Ragan and Jackson 1975). A second technique uses a mixture analysis to extract the percent of impervious area from various land use types (Ragan and Jackson 1975). This technique assumes that a pixel** contains more than one type of surface material. For example, in any urban area a pixel may contain grass, asphalt and buildings. The spectral reflectance of this pixel is the sum of the spectral reflectances of each surface material weighted by the proportion of the pixel that the material occupies. Each surface material has a variable response in each multispectral band, but the proportion of the pixel the material occupies remains constant.

The mixture analysis technique uses these facts to break up the spectral measurements to identify the proportion of each surface material present in the pixel. In one method the impervious surface material, represented by a spectral signature, that occurs in a pixel is incremented by 10% and summed to 100% for every possible combination of materials to establish a table of mixture signatures. A table can be developed containing the percent of impervious area for each element associated with a set of spectral radiance values for each of the Landsat multispectral bands. This technique assumes that there is a ratio that represents all 0-100% surface materials and that some curve can be fitted between the two extremes. This procedure is referred to as the ratio method.

The variety of surface materials in urban areas, the variability of pure spectral signatures, and the number of spectral measurements provided by Landsat all contribute to placing an upper limit on the accuracy of individual pixel estimates (Jackson 1975). Therefore, the computer processing of Landsat data was not used in this study. Estimation techniques produce errors which individual pixel estimates may cancel, especially as the total area increases in size. Also, an individual pixel covers approximately one-half a city block and at this resolution is unacceptable for use in the STORM model (Jackson 1975).

Objectives

The primary objective of this study was to compare the cost effectiveness of remote sensing techniques with that of the conventional techniques used by the U.S. Army Engineer Division, New England (NED), in the Boston Harbor-Eastern Massachusetts Metropolitan Area (EMMA) study to quantify the following parameters used in the STORM model:

1. Area of a watershed
2. Land use type in a watershed
3. Impervious surface area for a land use type
4. Curb length for a land use type

The secondary objective was to assess the usefulness of remote sensing in delineating water bodies, drainage patterns, and watershed and political boundaries.

** Impervious surface (9) is defined as paved streets, highways and sidewalks that can trap dust, dirt, rags, paper, vegetation, inorganics or other litter. Material that accumulates on street surfaces contributes significantly to pollutant discharge loading rates (U.S. Army Engineer Division, New England 1973a).*

† Curbs (10) perform a dual function by providing protected areas where dust and dirt can accumulate and by forming channels that collect and rapidly remove runoff (U.S. Army Engineer Division, New England 1973a).

*** Picture element. For Landsat imagery, a pixel is 57 x 79 m.*

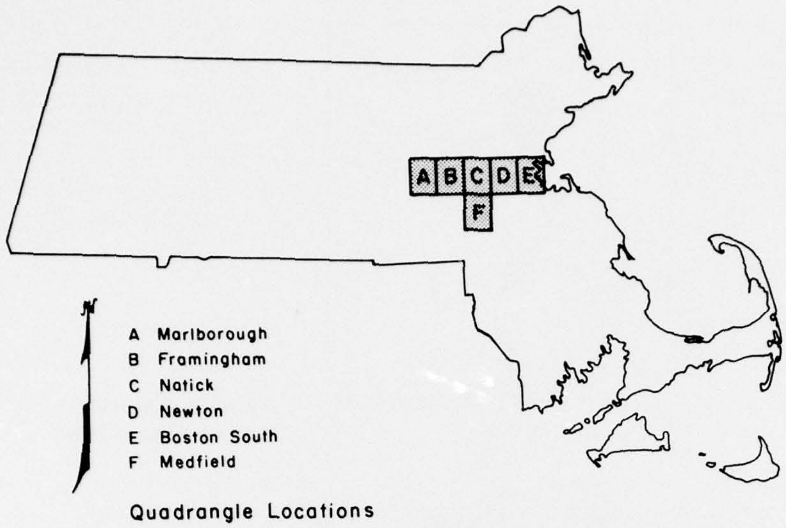

Figure 1. Location of the six 7½-minute quadrangles.

APPROACH

Imagery characteristics

Aerochrome infrared film, type 2443, obtained on 26 September 1973 from a NASA RB-57 aircraft was used in the mapping effort. The *9 x 9*-in. photography (scale 1:120,000) was taken at an altitude of 60,000 ft with an RC-8 camera. Selected NASA photographs were enlarged to the conventional scale (1:24,000) used in the NED Urban Studies program. These prints were made from black and white negatives prepared from the original NASA color infrared transparencies. Mapping on the black and white prints was facilitated by periodic reference to the color infrared transparencies as the tonal characteristics of land use, vegetative and agricultural units are more easily distinguished from color infrared data products (McKim et al. 1975).

Six 7½-minute quadrangles were selected as study sites by CRREL and NED personnel. They were the Boston South, Newton, Natick, Framingham, Marlborough and Medfield quadrangles located in Massachusetts (Fig. 1). Black and white photomosaics were assembled for each of the six areas from the NASA RB-57/RC-8 photography (scale 1:24,000). Land use maps were prepared from the photomosaics.

On 9 May 1975 a low altitude (2000 ft) aircraft mission was flown over selected sites in the Boston South, Natick, Newton and Framingham quadrangles to obtain photography for the impervious surface and curb density analyses. A Zeiss RMK 15/23 camera provided a black and white negative film in a 9 x 9-in. format (measured scale 1:3,500). Contact black and white prints of selected test areas in these quadrangles were prepared from the original black and white negative film.

Thematic mapping

Drainage, watershed and political boundaries. Hydrologic and political boundaries for each photomosaic were mapped on mylar film overlays (Appendix A). The hydrologic features, which included drainage patterns and water bodies, were easily delineated, as water appears dark blue or black on color infrared transparencies. Watershed boundaries were not delineated because there was insufficient overlap of the photography for stereo viewing. However, the watershed boundaries could be obtained from elevation contours and stream relationships observed on existing USGS topographic maps.

Political boundaries, which included the corporated town and county lines, could not be obtained with photointerpretation techniques, but were obtained from existing topographic maps. The political boundaries were included in the mapping exercise for location purposes.

Land use. The land use classification scheme (Table XI, page 15) selected for the land use mapping (Appendix A) was modified from USGS Circular 671, *A Land-Use Classification System for Use with Remote-Sensor Data* (Anderson et al. 1972). This scheme uses the best criteria of existing land use classification systems to the extent that they are amenable for use with remote sensing data products. The open-ended concept presented by Anderson can be used by regional, state and local agencies to develop detailed land use classification systems for compatibility with the national

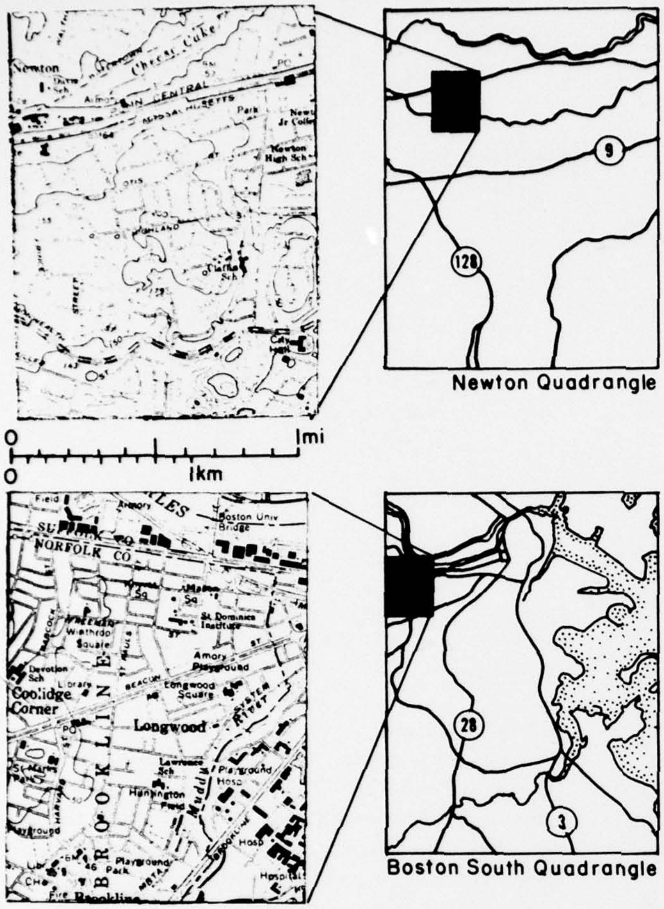

Figure 2. Sites used for the curb density and impervious surface analyses.

system. The first and second levels of the system described by Anderson were utilized in this study with a third level of classification added for detailed land use mapping. The level III land use units were selected based on parameters that directly influence water quality and quantity in the STORM model. The number of land use categories selected for input to the STORM model is presently limited to five, but more detailed land use maps may provide increased predictive capabilities in the modeling effort.

Six level I land use units were mapped on the NASA RB-57/RC-8 photography (Table XI). Subunit designations were made using the level II and level III land use units. For example, W2 refers to a lake within the level I unit *water*, and U9p refers to a park within the level II unit *open and other* as part of the level I unit *urban and built-up land.* Areas of land use which were too small to be mapped separately (less than 5 acres) were included in the land use unit where they occurred.

Impervious surfaces. The Boston South, Newton, Natick, Framingham and Marlborough quadrangles were selected for detailed analysis of impervious surfaces. Each quadrangle was divided into 36 equal areas. A random number analysis was run to obtain a 25% sample for each quadrangle. Each of the nine sections selected was examined using the USGS topographic quadrangles to determine the most suitable sites for acquisition of low altitude photography. Using this technique photographs were taken of a total of eight potential sites in the Framingham, Natick, Newton and Boston South quadrangles, representing a continuum from low to high urbanization. After the low altitude aircraft photography was reviewed, two representative sites were selected for impervious surface mapping (Fig. 2). One site, located in the Boston South quadrangle, was 1.54 square miles in area and represented a highly urbanized region. The second site of 1.39 square miles was located in the Newton quadrangle and was less urbanized.

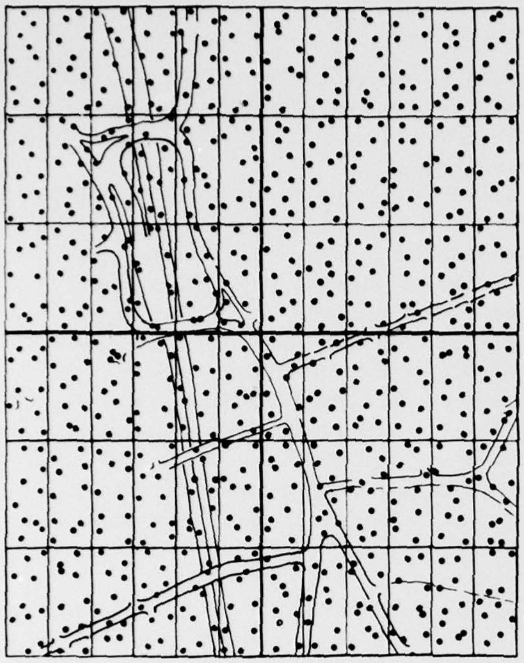

Figure 3. Random-dot pattern used in curb density analysis.

Approximately 50 photographs of each site were needed for adequate coverage. A working photomosaic was prepared of the two sites using every other photographic print. The remaining photographs could then be used for stereoscopic viewing to obtain detailed information on impervious surfaces.

The impervious surfaces, excluding rooftops, were opaqued on a mylar film overlay of the Newton and Boston South site photomosaics (Appendix B, Fig. B2 and B4). Impervious surfaces were defined as paved streets, highways, parking lots and sidewalks.

A land use map was prepared for each site (Appendix B, Fig. B1 and B3). The land use acreage and the acreage of impervious surfaces in each land use unit were quantified with an Antech, Inc. planimetric color densitometer. The overlay for each site was divided into 18 equal areas for ease of measurement and scale purposes on the densitometer. The land use overlay for each site was cut apart into separate land use categories. In addition, the overlay for impervious surface was cut apart so that cutouts of impervious surface per land use type were available. The percentage of each land use for the entire study area was determined by filling the rectangle, sometimes several times, with the opaque overlay of a particular land use. The desitometer determines the percentage of a unit and the operator then calculates the area based on knowledge of the rectangle size and scale used in the measurement. After this was accomplished for each land use category, then the impervious surface percentage and areal extent per land use category were determined using the same measurement procedure.

Curb density. The Newton photomosaic prepared during the impervious surface mapping was also used in the curb density analysis. The original 9 x 9-in. black and white negative film photography (measured scale 1:3,500) was viewed with a binocular microscope using a 0.7 power magnification. Curbs were easily observed on the negative film photography and then mapped on a mylar film overlay as linear extensions along streets and around the curves at intersections (Appendix C, Fig. C1).

A field trip to Newton provided the ground truth needed to verify the results of curb length measurements obtained with the photointerpretation method. The curbs identified during the field reconnaissance were transferred to a mylar film overlay (Appendix C, Fig. C2).

The curb lengths mapped using photointerpretation techniques and verified by ground truth data were quantified using a random-dot statistical method. The random-dot pattern used was a modification of aerograph chart no. 4849, Charles Bruning Company, Memphis, Tennessee (Cress and Link 1975). An overlay of the random-dot grid pattern was superimposed over the land use base map and overlay map of curb length. Figure 3 shows an example of the random-dot pattern superimposed on a portion of a curb length map. Each grid cell of the random-dot pattern represented 1.93 acres and contained 10 randomly distributed dots. The dots that intersected curbs in a specific land use unit were counted for the photointerpretation map and the procedure repeated using the ground truth map of actual curbs in the site. The total number of dots per land use unit for both maps was converted to a total curb length using the following equation (Cress and Link 1975):

$$\hat{L} = \frac{1}{\rho} \frac{\hat{k}}{2r}$$

where $\hat{L}$ = estimate of total length of curbs
ρ = density of dots per unit area
$\hat{k}$ = number of dots that intersect a curb ("hits")
2 = factor introduced because a dot can fall on either side of a curb
r = radius of the dots.

RESULTS AND DISCUSSION

Drainage, watershed and political boundaries

Hydrologic features, which included drainage patterns and water bodies, were easily delineated from the NASA RB-57/RC-8 photography using photo-interpretation techniques. However, the watershed boundaries could not be mapped using this technique because of insufficient stereo coverage. The political boundaries could be obtained only from USGS topographic quadrangle maps.

Land use (refer to Table XI, p. 15)

Remote sensing techniques. The level I unit *U*, urban and built-up land, included areas of intensive urban use with most of the land covered by buildings. This unit comprised nine level II units. Residential areas *U1* were easily recognized because of the characteristic uniform size and spacing pattern of houses, driveways and lawns. The two level III units mapped within unit *U1* were determined by evaluating housing density and its relationship to the surrounding urban setting. High density *U1h* represented multiple family housing or more than three families per acre, whereas low density *U1l* represented single-family housing or less than three families per acre.

The commercial and services unit *U2* included buildings used for the sale of products and services. Within this category two level III units were delineated: *U2b* and *U2r*. Central urban business districts often included institutions such as churches and schools which were too small in area to delineate separately.

The industrial unit *U3* included light manufacturing, industrial parks, and heavy industry such as steel mills and electrical power generating stations. Two level III units were mapped within this category: *U3l*, which included industrial parks, packing plants and warehouses located near urban areas or in relatively open country, and *U3t*.

The level II extractive unit *U4* included surface mining operations. In Boston these areas were primarily sand and gravel pits and stone quarries.

Four level III units were mapped within the level II unit of transportation, communications and utilities *U5*. Airport facilities included the runways, terminals, service buildings and parking lots and were usually surrounded by a perimeter fence. Major transportation routes such as interstate highways and railways were easily delineated because of characteristic linear patterns. Minor roads were not separated as a specific land use type, but were included within the land use unit where they occurred. Also, facilities for transporting water, gas, oil and electricity, airwave communications facilities, and transportation facilities such as docks and shipyards were placed within the *U5* category.

Included within the level II institutional unit *U6* were military bases, prisons and hospitals. All buildings, grounds and parking lots associated with an institution were included in the *U6* unit. One distinctive level III unit large enough in area to be mapped separately was educational campuses *U6e*.

The level II strip and clustered settlement unit *U7* was not subdivided. This category contained strip developments along transportation routes. Also, the level II mixed category *U8* was not subdivided. This unit was mapped in large urban areas where mixtures of land use types occurred. Five level III land use units were mapped within the level II open and other unit *U9*.

The level I unit agricultural land *A* included land primarily used for the production of cash crops. These areas were characterized by fewer buildings and roads than occurred in urban areas, a lower concentration of population and urban activity, and farming activities. Two level II units were differentiated. The cropland and pasture unit *A1* was further subdivided into two level III units. Orchards *A2* were easily delineated due to the linear spacing between rows of trees.

The third level I unit, forest land *F*, was defined as land that was at least 10% covered with trees. Only mixed forest land was mapped.

The fourth level I unit *W* comprised areas predominantly covered by water. Water bodies of less than 5 acres and very small stream tributaries were not delineated, but were included in the land use in which they occurred. Four level II units were mapped within the water category.

The fifth level I unit, nonforested wetlands *N*, comprised seasonally flooded basins such as meadows, marshes and bogs. It should be recognized that consistent and uniform identification of wetland areas will change due to tide, rainfall and other climatic variations. The nonforested wetlands unit was subdivided into two level II units. *N1* included areas with less than 10% tree cover or nonwoody vegetation and *N2* included non-vegetated tidal flat and swamp areas.

The last level I unit, barren land *B*, consisted of land with limited ability to support life, for example sand and rocks. In Boston these areas were primarily beaches.

A total of 6 level I, 18 level II and 18 level III land use units were delineated on the six quadrangles using the RB-57/RC-8 photographs as a data base. These land use units were selected on the basis of their

significance in affecting water quality and quantity as used in the STORM model.

Conventional techniques. Present land use data (1970-71) were developed by NED from panchromatic aerial photography at a scale of 1:20,000 (MacConnell 1971). The data from MacConnell were tabulated in 100 land use categories for towns located in the study area and transferred to USGS quadrangle sheets (scale 1:24,000). However, for the NED study these 100 land use units were combined into five urban land use categories: single-family residential, multi-family residential, commercial, industrial, and urban open. For each town the approximate area of the five urban land use categories within each hydrologic division (watershed) was determined through an analysis of USGS quadrangle maps and prior knowledge of the area. Land use acreage was determined for hydrologic divisions within towns from projected land use data obtained from a socioeconomic analysis of the same study area (Metcalf & Eddy, Inc. 1973).

Costs. The average cost of mapping land use in the six 7½-minute quadrangles is shown in Table I. The NASA RB-57/RC-8 data products can be obtained from the EROS Data Center, Sioux Falls, South Dakota.

Table I. Costs of mapping land use using remote sensing (CRREL) and conventional (NED) techniques.

	CRREL	*NED*
Purchase of RB-57/RC-8 data products	$540	
Enlargement of photography	$350	
Assembling and mapping of six 7½-minute quadrangles	$2000 (236 hours)	
Total cost	$2890	$600
Total cost per acre	$0.014	$0.003

The costs shown in Table I do not include preliminary planning, coordination meetings, drafting, literature review, overhead, publication, the NASA RB-57 mission or preparation of the final report. There would also be additional costs if it were necessary to consolidate the land use units into five units similar to those used by NED.

It is difficult to compare the photointerpretation costs with those of the NED land use mapping effort. The cost of mapping and developing acreage statistics for 100 land use units per community using conventional techniques was estimated to be about $100/quadrangle or about $0.003/acre (Satterwhite pers. comm. 1974). However, this was accomplished under a university contract and did not include the cost of photographic data products, enlargement of photography or the assembling of photomosaics.

Impervious surfaces

Remote sensing techniques. The percentage of impervious surface in each land use category in the Newton and Boston South sites (Fig. 2) was determined using an Antech, Inc. planimetric color densitometer as described previously. The results of these analyses are presented in Tables II and III.

The percentage of impervious surface in both sites was generally less than 15% in the *U9*, *U9p* and *U4* land use units (refer to Table XI). Cemeteries were the exception, containing approximately 20% impervious surface. Intermediate values of 16 to 30% impervious surface occurred in the *U1h*, *U1l* and *U6e* land use categories. The largest values computed for impervious surface were in the *U2*, *U2b*, *U2r*, *U5h* and *U6* land use categories and ranged from 30-89% depending on the degree of urbanization. The more highly urbanized Boston South site had a smaller impervious surface percentage in the commercial land use category than did the less urbanized Newton site. This result probably reflects the construction of large shopping centers in suburban areas.

Conventional techniques. The degree of imperviousness of each of the five land use categories for the NED study was based on analysis of aerial photographs of several towns in the Boston area, USGS quadrangle maps and a review of current literature (U.S. Army Engineer Division, New England 1973b, Stankowski 1972, Chow 1964). This information was used in computing a runoff coefficient for the STORM model which represents losses due to infiltration. The coefficient is weighted by the areal extent of each land use category and incorporates two runoff coefficients common to all land uses. One is for impervious surfaces (0.9) and one for pervious surfaces (0.15). In the STORM model the runoff computed using the weighted coefficients represents the hourly peak rate of runoff from the urban land area only (U.S. Army Engineer Division, New England 1973a).

The relationship between imperviousness and land use obtained using remote sensing and conventional techniques is shown in Table IV. The land use units from the remote sensing study (Table XI) were combined (column 1) to conform to the land use units used in the NED study (column 3). The impervious

Table II. Impervious surface area for Newton site.

Land use	Total land use area (acres)	Percentage of site (%)	Impervious surface area (acres)	Impervious surface per land use (%)
U1h	156.9	15.9	27.2	17.3
U1l	650.2	66.0	102.5	15.8
U2b	41.2	4.2	30.7	74.5
U2r	15.7	1.6	12.6	80.2
U4	26.0	2.6	1.1	4.2
U5h	45.8	4.6	34.4	75.1
U6e	23.7	2.4	5.4	22.8
U9c	14.4	1.5	2.9	20.1
U9p	3.2	0.3	0.1	3.1
F1	8.4	0.9	0.0	0.0
Total	985.5	100.0	216.9	

Table III. Impervious surface area for Boston South site.

Land use	Total land use area (acres)	Percentage of site (%)	Impervious surface area (acres)	Impervious surface per land use (%)
U1h	489.7	55.0	147.0	30.0
*U2**	130.7	14.7	52.6	40.2
U2r	39.9	4.5	11.8	29.6
U5h	81.7	9.2	72.6	88.9
*U6**	8.0	0.9	4.4	55.0
U6e	18.2	2.0	5.1	28.0
*U9**	8.5	1.0	1.2	14.1
U9p	38.4	4.3	5.3	13.8
F1	29.9	3.4	3.0	10.0
W	44.1	5.0	0.0	0.0
Total	889.1	100.0	303.0	

* These include areas that were not differentiated further to the level III classification.

Table IV. Extent of impervious surfaces determined using remote sensing (CRREL) and conventional (NED) techniques.

Land use CRREL	Impervious surface CRREL (%)	Land use NED	Impervious surface NED (%)
U1l	16	Single-family residential	25
U1h	27	Multi-family residential	45
U2, U6, U7, U8	44	Commercial	60
U5	84	Industrial	80
U4, U9	12	Urban open	10

surface (column 2) was determined by using a weighted average from the respective impervious surface percentages shown in Tables II and III.

The industrial and urban open impervious surface percentages obtained using remote sensing and conventional techniques compared favorably (Table IV). For the remaining land use categories a smaller impervious surface area was found with remote sensing techniques than with conventional techniques. The rooftops were estimated from quadrangle sheets using conventional techniques, but were not included in the determination of impervious surface using remote sensing. If rooftops had been included in the remote sensing technique, the impervious percentages in the single-family residential, multi-family residential and commercial land use units would remain below the percentages computed using the conventional procedure. The procedure used by NED probably overestimates impervious surfaces, whereas the remote sensing technique underestimates them. However, the remote sensing procedure is considered to be more accurate than the conventional method, primarily because ground truth measurements indicate that 90% of the impervious area was accurately mapped using that technique.

Costs. The average costs of mapping impervious surface for the two sites using remote sensing techniques are shown in column 1 of Table V. The average costs using conventional techniques were determined by a one-day analysis of the entire EMMA study area and do not include all the expenses of the mapping effort (column 2 of Table V). Therefore, sufficient information was not available to compare the total costs of remote sensing with the conventional procedures.

Table V. Costs of mapping impervious surfaces using remote sensing (CRREL) and conventional (NED) techniques.

	CRREL	*NED*
Acquiring photography	$700	
Processing and developing film and photographs	$700	
Assembling and preparing two photomosaics	$150	
Mapping impervious surface	$1350 (152 hr)	$100 (8 hr)
Total cost	$2900	$100
Total cost per acre	$1.55	

Curb density

Remote sensing techniques. The techniques described previously for mapping curb density were used to determine the length of curbs in each land use category for the Newton site. The results from the random-dot count technique are presented in Table VI. This technique was applied to the photointerpretation map and the ground truth map of curb length prepared for the Newton site. A "hit" represents a dot intersecting a curb on the curb length map.

Comparison of the number of "hits" on the photointerpretation and ground truth maps revealed that greater than 64% of the curbs were identified using the photointerpretation technique (column 6 of Table VI). An overestimation was made in the *U2b* and *U5h* land use units, but this is attributed to the fact that there were more linear features in these units.

Table VII compares curb length measured for the Newton site with ground truth observations. The most curbs were found in the *U1l* land use unit probably because of recent urban expansion. The least curb length was found in the *U2r*, *U6e* and *U9c* land use units. The remaining curb density values for the *U1h*, *U2b* and *U5h* land use units showed intermediate values varying from 73-237 ft/acre.

Conventional techniques. In the NED study the curb densities for the five land use categories were developed through an analysis of 20 test areas comprising 1094 acres selected from USGS quadrangle sheets and were scattered throughout the entire EMMA study area. Curbs were assumed to occur along both sides of the streets. The curb density for each land use varied with the degree of urbanization. Therefore, using residential density as an index of urbanization, an analysis was made of the relationship between curb density and land use type. Table VIII shows these results.

It was assumed for the Newton site that the population density would probably not exceed 700 persons/square mile. Therefore, line 1 of Table VIII contains the only values that could be compared to the remote sensing results. The curb length measurements using remote sensing techniques (column 2 of Table IX) were determined using a weighted average from the respective curb densities shown in Table VII. A comparison was made between the remote sensing and conventional techniques of curb length determination (Table IX). In three out of five land use categories the curb length values were significantly lower when remote sensing techniques were used. This may have been because the Newton site was not truly representative or because the conventional techniques overestimated the length of curbs since they assumed that both sides of the streets were curbed. In the Newton site curbs very often occurred only on one side of the street

Table VI. Random-dot analysis of curb length for the Newton site.

Land use	Total land use area (acres)	Percentage of site (%)	Photointerpretation map (hits)	Ground truth map (hits)	Ratio col. 4/col. 5
U1h	156.9	15.9	82	123	0.67
U1l	650.2	66.0	187	252	0.74
U2b	41.2	4.2	44	38	1.16
U2r	15.7	1.6	9	14	0.64
U4	26.0	2.6	0	0	0.0
U5h	45.8	4.6	109	103	1.06
U6e	23.7	2.4	10	15	0.67
U9c	14.4	1.5	3	3	1.0
U9p	3.2	0.3	0	0	0.0
F1	8.4	0.9	0	0	0.0
Total	985.5	100.0			

Table VII. Curb lengths for Newton site using the random-dot procedure.

Land use	Photointerpretation (ft/acre)	Ground truth (ft/acre)
U1h	158.3	236.9
U1l	360.9	486.4
U2b	84.9	73.3
U2r	17.4	27.0
U5h	210.4	198.9
U6e	19.3	28.9
U9c	5.8	5.8

Table VIII. Curb densities determined using conventional (NED) techniques.
From U.S. Army Engineer Division, New England, 1973a.

Residential density (households/ac)	Population density (persons/mi²)	Single-family residential (ft/ac)	Multi-family residential (ft/ac)	Comm (ft/ac)	Indus (ft/ac)	Urban open (ft/ac)
1-2	< 700	300	400	300	250	250
3-5	700-4000	400	500	400	350	250
>5	> 4000	500	600	600	400	250

or intermittently on one or both sides. In addition, NED may have included safety factors in the calculations that would overestimate the ft/acre of curb length in the multi-family residential, commercial and urban open land use categories. The values of curb density for the single-family residential were 17% less using conventional techniques than with remote sensing procedures. The values for the industrial curb length measured by conventional techniques were overestimated by 16% when compared with the values obtained using remote sensing techniques.

Costs. The average cost of mapping curb length for an area of two square miles using remote sensing techniques is shown in Table X. The acquisition of the photography, processing and development of the film and photographs, and assembling and preparation of the photomosaic were not included as these costs were calculated previously in the impervious surface

Table IX. Curb length measurement using remote sensing (CRREL) and conventional (NED) techniques.

Land use (CRREL)	*Curb length (CRREL) (ft/acre)*	*Land use (NED)*	*Curb length (NED) (ft/acre)*
U1l	361	Single-family residential	300
U1h	158	Multi-family residential	400
U2, U6	59	Commercial	300
U5	210	Industrial	250
U4, U9	3	Urban open	250

Table X. Costs of mapping curb length using remote sensing (CRREL) and conventional (NED) techniques.

	CRREL	*NED*
Curb density mapping	$800 (60 hr)	$1300 (104 hr)
Cost per acre	$0.90	$1.20

mapping exercise. The average costs for the conventional method were based on determining curb density for 20 test areas comprising 1094 acres for the entire EMMA study area.

The cost of using remote sensing techniques is less than the cost of using conventional techniques. The conventional techniques were used on 20 test sites of limited acreage. If more extensive analysis had been accomplished the costs might have increased. Also, the accuracy of determining curb length using the remote sensing method compares favorably to ground truth measurements (Table VII). There were no ground truth measurements available for comparison with curb length values determined using conventional techniques; therefore, the accuracy of this procedure could not be assessed.

CONCLUSIONS

Watershed and political boundaries could not be mapped from NASA high altitude aircraft photography using remote sensing techniques. Watershed and political boundaries would have to be obtained from existing USGS topographic maps. Hydrologic features such as lakes and streams could be delineated on a cost effective basis from NASA RB-57/RC-8 high altitude aircraft photography with restrictions occurring only on resolution.

A total of 6 level I, 18 level II and 18 level III land use categories were mapped for six selected 7½-minute quadrangles located in the Boston area (Appendix A). These units were delineated from black and white photomosaics prepared from NASA RB-57/RC-8 high altitude aircraft photography enlarged to a scale of 1:24,000. The cost of the land use mapping using photointerpretation techniques was $0.014/acre or a total of $2890 for the six quadrangles. This compares to costs of $0.003/acre or a total of $600 using conventional techniques. However, the conventional procedure did not include the cost of photographic data products, enlargement of photography or the assembling of photomosaics, which would greatly increase the total costs. If these costs were included, the two procedures would probably be comparable.

Impervious surface was mapped from low altitude aircraft photography (measured scale 1:3500) for two sites in the Boston South and Newton quadrangles. The percentage of impervious surface determined using remote sensing techniques compared favorably to that calculated conventionally. The cost of using remote sensing techniques was $1.55/acre; however, there was not sufficient information available to compare these costs to the conventional procedures used by NED. Since all highways, parking lots, roads, etc. were easily delineated using the remote sensing technique, this technique would be much more accurate than that used by NED.

More than 64% of all curbs located in the Newton site were identified from low altitude (measured scale 1:3,500) aircraft photography using remote sensing techniques. A random-dot statistical method was used to obtain a total ft/acre curb length measurement for various land use units. The curb density for each land use found by conventional techniques varied with the degree of urbanization when using residential density as an index of urbanization. The cost of curb density mapping was $0.90/acre using remote sensing techniques and $1.20/acre using conventional techniques. An evaluation of the accuracy of measuring curb length using conventional techniques could not be made because ground truth data were not obtained.

RECOMMENDATIONS

The following recommendations are made based on the accuracy of the measurement conducted in the study and on the cost comparisons between remote sensing and conventional methodologies.

1. The NASA RB-57/RC-8 photography enlarged to a scale of 1:24,000 provides adequate detail for land use mapping of categories needed for the STORM model. This photography should be used in the Corps of Engineers Urban Studies Program when mapping accuracy can be accomplished with a resolution of 5 meters. The cost of a black and white negative (9 x 9 in.) covering 14.7 nmi^2 is $6.00; color is $12.00.

2. NASA RB-57/RC-8 photography cannot be used in the analysis for impervious surface or curb density determinations. Low altitude photography must be used to obtain the accuracy needed for the STORM model. Adequate resolution for the quantification of curb density to an accuracy greater than 64% can be obtained using data products obtained from a Zeiss RMK 15/23 mapping camera flown at 2000 ft (measured scale 1:3,500).

The remote sensing procedures used in this study provided much greater detail than conventional procedures. The increased accuracy provides more confidence in the predictive capability of the STORM model. The remote sensing procedures were not always cost effective when compared to the conventional procedures, but the remote sensing method was more accurate when compared to ground truth data. Therefore, remote sensing techniques should be used and appropriate photographic resolution and scale factors taken into consideration when mapping parameters used in the Corps of Engineers Urban Studies Program. Specifically, these remote sensing techniques could be used to quantify land use, impervious surface and curb density values for use in the STORM model.

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Table XI. Land use classification system (modified from Anderson et al. 1972).

Color (App. A)	Level I	Level II	Level III
	U. Urban and built-up land	1. Residential	h. high density (> 3 families/acre) l. low density (< 3 families/acre)
		2. Commerical and services	b. business, central urban r. retail trade and offices
		3. Industrial	l. light industry t. tank farms
		4. Extractive	
		5. Transportation, communications and utilities	a. airports r. railroads h. limited access highways w. water treatment plants
		6. Institutional	e. educational campuses
		7. Strip and clustered settlement	
		8. Mixed	
		9. Open and other	g. golf courses c. cemeteries t. transitional areas under construction p. parks o. open
	A. Agricultural land	1. Cropland and pasture	o. open, barren c. closed, vegetated
		2. Orchards	
	F. Forest land	1. Mixed	
	W. Water	1. Streams and waterways	
		2. Lakes	
		3. Reservoirs	
		4. Bays and estuaries	
	N. Nonforested wetlands	1. Vegetated	
		2. Bare	
	B. Barren land		

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